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ABSTRACT

We find no evidence for ν_μ or $\bar{\nu}_\mu$ decays for any two-body decay mode in which a photon is emitted. The 90% confidence level limit which we set is $\tau_{\nu_\mu}/M_{\nu_\mu} > 0.11$, where M_{ν_μ} is the mass of the muon neutrino in eV and τ_{ν_μ} is the muon neutrino lifetime in seconds.

Presented by R. L. Burman

Much interest has recently been focused on the subject of lepton flavor conservation. In particular, there has been extensive experimental and theoretical investigation of the possibility of neutrino oscillations. The formalism which allows neutrinos to oscillate into each other could also allow neutrino decay. Specifically, in order for a muon neutrino to decay, it is necessary that it have a nonzero rest mass, that there be an interaction which breaks the lepton number conservation scheme, and that there be an odd half-integer spin particle which is lighter than the muon neutrino.

We have calculated the sensitivity of our recent neutrino experiment at the Clinton P. Anderson Meson Physics Facility (LAMPF) to the decay of ν_μ or $\bar{\nu}_\mu$. This experiment has previously been used to set new limits on exotic muon decay,[1]

$$R(\mu^+ \to \bar{\nu}_e/\mu^+ \to \text{all}) < 0.09 \quad ;$$

to measure for the first time the weak matrix element involved in energy production in the sun,[1]

$$\sigma(\nu_e D \to p e^- p) = (0.52 \pm 0.18) \times 10^{-40}\ \text{cm}^2 \quad ;$$

and to limit the mass difference in the $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation channel,[2]

$$\delta m^2 < 0.9\ \text{eV}^2$$

The six-ton H_2O Cherenkov counter[3] was sensitive to any neutrino decay within the volume of the detector in which a γ was emitted and which subsequently converted in the H_2O radiator. Our counter was exposed to an incident flux of 1.7×10^{18} muon neutrinos which originated from $\pi^+ \rightarrow \mu^+\nu_\mu$ decays and to the same flux of $\bar{\nu}_\mu$ and ν_e from the subsequent $\pi^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$ decays. Both decays occurred at rest within the main proton beam stop at LAMPF. The neutrino spectra from the stopped π^+ and μ^+ decays are shown in Fig. 1; the maximum neutrino energy is 53 MeV. At the position of our water Cherenkov detector, the flux of each neutrino type was approximately 1.7×10^7 neutrinos/cm^2-s. Since the π^- and μ^- were mostly absorbed, the ratio of $\bar{\nu}_e$ to ν_e was less than 10^{-3}.

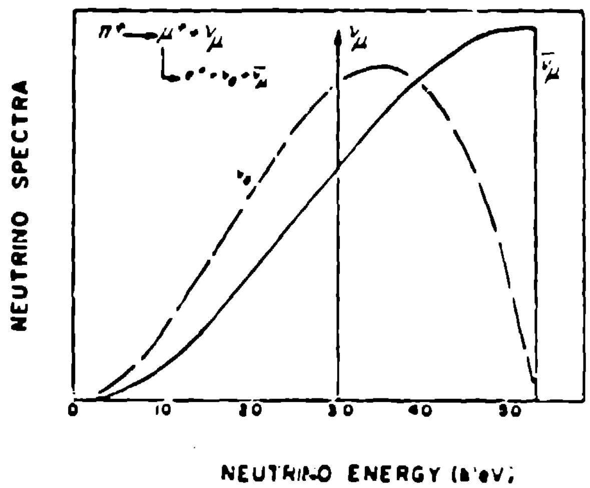

Fig. 1. Neutrino spectra from stopped π^+ and μ^+ decay at LAMPF beam stop.

The kinematics of the decay of a neutrino into two lighter particles, $\nu \rightarrow X + \gamma$, gives $E_\gamma = 1/2\ (1 + \cos\theta^*)E_\nu$, where we assume $E_\nu >> M_\nu$ and $E_\nu >> M_X$. Here E_γ and E_ν are energies in the laboratory system and θ^* is the angle of the photon in the center-of-mass system of the neutrino. The most general matrix element which might describe the decay of a spin 1/2 neutrino into another spin 1/2 particle and a photon would lead to an angular distribution of the form $(1 + a \cos\theta^*)$, where the asymmetry parameter a is related to the parity violation in the decay and to the initial polarization of the neutrino and must lie between -1 and +1.

A Monte Carlo program which was previously used to determine the gain and resolution of the Cherenkov counter[3] was modified to calculate the sensitivity of the counter to the decay of a ν and the subsequent conversion of the emitted photon. We fit the resulting distribution into the energy spectrum measured by our H_2O counter after cosmic ray and beam-associated high-energy neutron and known neutrino backgrounds were subtracted out.[1] We have found that the energy region below 25 MeV is contaminated with pile-up from thermal neutrons which came predominantly within the LAMPF beam gate and could thus not be subtracted out. Essentially no sensitivity remains in the energy region above 55 MeV. We, therefore, choose our analysis region to be from 25 to 55 MeV. Figure 2 shows our background subtracted energy spectrum. The curves show the results of the Monte Carlo calculations for ν_μ and $\bar{\nu}_\mu$ and for the asymmetry parameter a = +1 and a = -1. The normalization of these curves has been chosen to correspond to the previous best experimental upper limit of the sum of $\nu_\mu + \bar{\nu}_\mu$ decays, $\tau/M > 2.6 \times 10^{-2}$ s/eV (90% confidence level).[4]

We observe no evidence supporting ν_μ or $\bar{\nu}_\mu$ decay, and so we quote an upper limit to ν_μ or $\bar{\nu}_\mu$ decay at the 90% confidence level. The results for our experiment for ν_μ and $\bar{\nu}_\mu$ as a function of a is plotted in Fig. 3. In

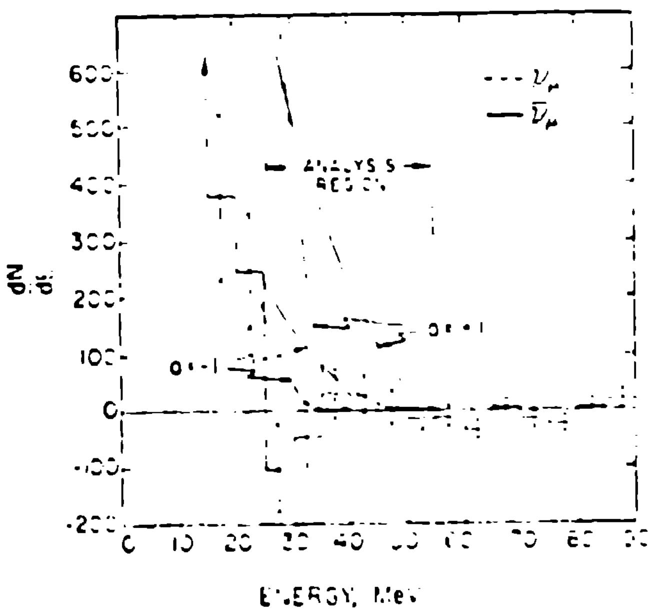

Fig. 2. Background-subtracted energy spectra from ν_μ and $\bar{\nu}_\mu$ decays for a = +1 and $\tau_{\nu_\mu}/M_{\nu_\mu}$ = 0.026 s/eV.

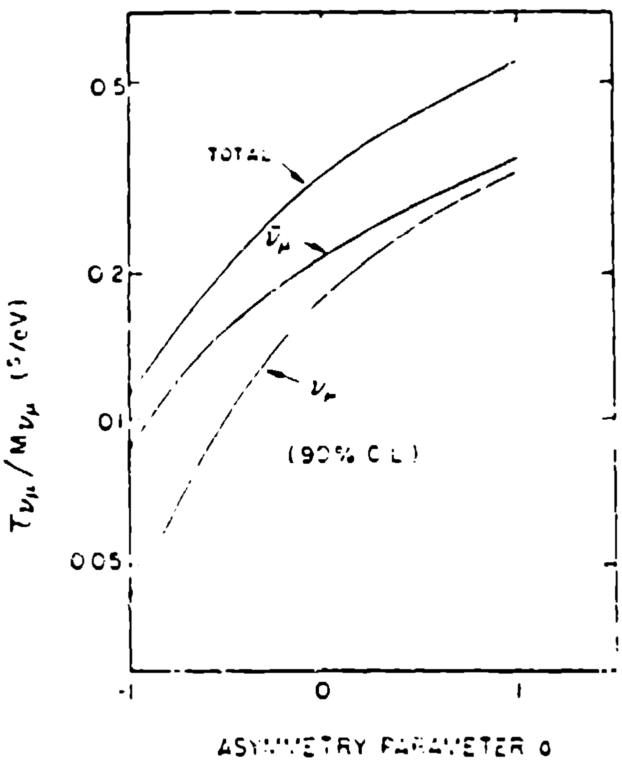

Fig. 3. Upper limits on muon-neutrino lifetime for ν_μ, $\bar{\nu}_\mu$, and total ($\nu_\mu + \bar{\nu}_\mu$) vs asymmetry parameter a.

order to extract a single number for the sensitivity to the sum of ν_μ and $\bar{\nu}_\mu$ decays, we assume that the dominant mode of the decay is CP-conserving so that the decay rates and the center-of-mass angular distributions are the same for $\nu_\mu \to \gamma + x$ as for $\bar{\nu}_\mu \to \gamma + \bar{x}$. For normal neutrino production, where ν_μ are produced with negative helicity and $\bar{\nu}_\mu$ are produced with positive helicity, and for maximal parity-violating weak decay, we expect the asymmetry parameter $a = \pm 1$. Furthermore, from an explicit calculation of the matrix element in which only left-handed charged currents participate,[5] we have that $a = -1$.

So choosing the asymmetry parameter $a = -1$, which also corresponds to the lowest sensitivity of our experiment and summing over ν_μ and $\bar{\nu}_\mu$ decays, we obtain our result $\tau_{\nu_\mu}/M_{\nu_\mu} > 0.11$ at the 90% confidence level, where M_{ν_μ} is the mass of the muon neutrino in eV and τ_{ν_μ} is its mean life in seconds. This represents a factor of 4 improvement over the best previous experimental limits.[4]

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